

Mechanical Properties of Concrete by Incorporating Cementitious Materials (Rice Husk Ash, Fly Ash and Marble Powder)

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Abstract- This study experimentally investigates the influence of Rice Husk Ash (RHA), Fly Ash (FA), Marble Powder (MP) and Expanplast SP100 on hardened properties of concrete. A total of 14 concrete mixtures were prepared, including a control mixture and modified mixtures containing individual and combined replacements of RHA, FA, and MP, while 1% Expanplast SP100 was incorporated in the modified mixtures. Mechanical properties were assessed through 28-day compressive, splitting tensile and flexural strength tests. The results demonstrated that moderate replacement levels generally improved the mechanical properties of concrete. The 10% RHA mixture achieved a compressive strength of 33.92 MPa, compared with 30.00 MPa for the control mixture, representing an improvement of 13.07%. The corresponding splitting tensile strength increased from 2.85 MPa for the control to 3.24 MPa, an improvement of 13.68%. For flexural strength, the 10% RHA mixture achieved 4.76 MPa compared with 4.20 MPa for the control, representing an increase of 13.33%. The highest overall performance was obtained from the ternary mixture containing 5% RHA, 5% FA, and 5% MP, which achieved compressive, splitting tensile and flexural strengths of 35.10, 3.40, and 4.95 MPa, respectively. These values correspond to improvements of approximately 17.0%, 19.30%, and 17.86%, respectively, compared with the control concrete. The improvement is attributed to the combined effects of pozzolanic reactions, filler action, improved particle packing, pore refinement and enhanced cement-particle dispersion provided by Expanplast SP100. The findings demonstrate that the combined utilization of agricultural and industrial waste materials can provide a technically effective and more sustainable approach to concrete production while reducing dependence on conventional cementitious materials.

Keywords: Rice Husk Ash (RHA); Fly Ash (FA); Marble Powder (MP); Expanplast SP100; Sustainable Concrete; Supplementary Cementitious Materials; Compressive Strength; Splitting Tensile Strength; Flexural Strength; Waste-Based Concrete.

I. INTRODUCTION

Concrete is the most extensively used construction material worldwide owing to its high compressive strength, durability, versatility, and cost-effectiveness (Abir et al., 2026). It plays a fundamental role in the development of residential buildings, bridges, highways, dams, tunnels, industrial facilities, and other critical infrastructure (Pooja lakshmi et al., 2026). The increasing pace of urbanization and industrialization has resulted in an unprecedented demand for concrete, making it the backbone of modern construction (ODIBELI, C. C. 2025). Despite its outstanding engineering

properties, conventional concrete production relies heavily on Ordinary Portland Cement (OPC), the manufacturing of which is highly energy-intensive and responsible for approximately 7–8% of global anthropogenic carbon dioxide (CO₂) emissions (Horpibulsuk et al., 2003). The growing environmental concerns associated with cement production have encouraged researchers and engineers to develop sustainable alternatives that can reduce the carbon footprint of concrete while maintaining or enhancing its mechanical performance (Al Hassan et al., 2024). One of the most promising approaches to sustainable concrete technology is the partial replacement of cement with supplementary cementitious materials (SCMs)

(Kanchanasorn, al., al., 2018). These materials are generally industrial or agricultural by-products that possess pozzolanic or filler characteristics capable of improving the physical and mechanical properties of concrete (Zhang, Y. 2017). Among the widely investigated SCMs, Rice Husk Ash (RHA), Fly Ash (FA) and Marble Powder (MP) have attracted considerable attention because of their abundance, low cost and environmental benefits (Kanchanasorn, V. 2018). The incorporation of these waste materials into concrete not only decreases cement consumption but also provides an effective solution for managing industrial and agricultural wastes that would otherwise be disposed of in landfills.

Rice Husk Ash is an agricultural by-product generated during the combustion of rice husks and is characterized by its high amorphous silica content. The pozzolanic reaction between the silica present in RHA and calcium hydroxide released during cement hydration forms additional calcium silicate hydrate (C-S-H) gel, leading to a denser microstructure and improved long-term mechanical properties. Numerous studies have reported that optimum incorporation of RHA significantly enhances compressive strength, reduces permeability, and improves resistance to aggressive environmental conditions. However, the extremely fine and porous nature of RHA increases the water demand of concrete, often resulting in reduced workability when higher replacement levels are adopted.

Fly Ash, a by-product of coal-fired thermal power plants, has been extensively utilized in concrete because of its pozzolanic characteristics and spherical particle morphology. The spherical particles improve the flowability of fresh concrete by acting as microscopic ball bearings, while the pozzolanic reaction contributes to the formation of additional hydration products during later curing stages. Previous investigations have demonstrated that Fly Ash enhances long-term compressive strength, reduces the heat of hydration, improves durability and decreases permeability (Felekoğlu, B., & Sarıkahya, H. 2008).

Marble Powder is another promising supplementary material generated in large quantities from marble

processing industries. Disposal of marble waste creates serious environmental problems due to land occupation and dust pollution. Owing to its extremely fine particle size, Marble Powder primarily acts as a micro-filler that improves particle packing density, refines pore structure, and reduces internal voids within the cement matrix. The filler effect contributes to enhanced early-age strength and improved surface finish. However, because Marble Powder exhibits limited pozzolanic activity, excessive replacement of cement may reduce the availability of hydration products and consequently decrease the mechanical performance of concrete.

II. RESEARCH GAP AND NOVELTY

Extensive research has been conducted on the use of supplementary cementitious materials (SCMs), particularly Rice Husk Ash (RHA), Fly Ash (FA), and Marble Powder (MP), as partial replacements for Ordinary Portland Cement (OPC). Previous studies have demonstrated that these materials can improve concrete sustainability while enhancing selected mechanical and durability properties when used individually. RHA has been reported to increase long-term strength due to its high pozzolanic reactivity, Fly Ash improves workability and later-age strength through secondary hydration, and Marble Powder acts as a micro-filler that refines the pore structure and enhances particle packing. The novelty of the present research lies in the development and evaluation of a sustainable hybrid cementitious system incorporating Rice Husk Ash, Fly Ash, and Marble Powder together with Expanplast SP100 as a polycarboxylate ether-based superplasticizer. Unlike previous studies that primarily investigated individual or binary supplementary cementitious materials, this study evaluates the synergistic behavior of three waste-derived materials within a single concrete matrix. The research provides a comprehensive assessment of fresh and hardened concrete properties by simultaneously investigating slump, compressive strength, splitting tensile strength and flexural strength under identical experimental conditions.

III. MATERIALS AND METHODS

Materials

The experimental investigation was conducted using Ordinary Portland Cement (OPC), natural river sand as fine aggregate, crushed stone as coarse aggregate, potable water and Expanplast SP100 as a high-range water-reducing admixture (superplasticizer). All materials were selected in accordance with relevant ASTM standards to ensure consistency and reliability of the experimental results.

Ordinary Portland Cement

Portland Cement (OPC) conforming to ASTM C150 Type I was used as the primary binder throughout this study. The cement was procured from a local manufacturer and stored under dry laboratory conditions prior to use. The chemical properties of the cement were determined according to the relevant ASTM standards to verify its suitability for structural concrete Table 1. The test results indicated that the cement satisfied the specification requirements regarding fineness, specific gravity, consistency, setting time and compressive strength.

Rice Husk Ash (RHA)

Rice Husk Ash (RHA) was obtained from controlled burning of rice husks followed by grinding to obtain a fine powder. Due to its high silica content, RHA

possesses excellent pozzolanic properties and reacts with calcium hydroxide during cement hydration to form additional calcium silicate hydrate (C-S-H) gel. This reaction contributes to improved strength and durability of concrete. Before use, the chemical properties of RHA were determined as given in Table 1.

Fly Ash (FA)

Class F Fly Ash obtained from a coal-fired thermal power plant was used as a supplementary cementitious material. The material possesses spherical particles that improve workability and contribute to long-term strength through pozzolanic reactions. The physical and chemical characteristics of Fly Ash are presented Table 1.

Marble Powder(MP)

Marble Powder (MP) was collected from a local marble processing industry. The material mainly consists of calcium carbonate and acts as a micro-filler in concrete. Its fine particle size improves particle packing and reduces pore volume, thereby enhancing the compactness of the cement matrix. The measured physical and chemical properties are summarized Table 2.

Table 2. Chemical Composition of Ordinary Portland Cement (OPC), Rice Husk Ash (RHA), Fly Ash (FA) and Marble Powder (MP)

Oxide Composition (%)	OPC	RHA	FA	MP	Standard Requirement	Test Standard
Silicon Dioxide (SiO ₂)	21.3	89.6	56.8	1.8	—	ASTM C114 (XRF)
Aluminum Oxide (Al ₂ O ₃)	5.4	0.9	24.5	0.5	—	ASTM C114 (XRF)
Ferric Oxide (Fe ₂ O ₃)	3.2	0.6	7.2	0.2	—	ASTM C114 (XRF)
Calcium Oxide (CaO)	63.5	2.3	5.1	54.8	—	ASTM C114 (XRF)
Magnesium Oxide (MgO)	2.1	0.7	1.8	0.8	≤ 5.0% (SCMs)	ASTM C114 (XRF)
Sulfur Trioxide (SO ₃)	2.7	0.3	0.4	0.1	≤ 5.0%	ASTM C114 (XRF)
Potassium Oxide (K ₂ O)	0.6	2.1	1.4	0.2	—	ASTM C114 (XRF)
Sodium Oxide (Na ₂ O)	0.3	0.4	0.5	0.1	—	ASTM C114 (XRF)
Loss on Ignition (LOI)	2.4	4.8	3.2	42.5	≤ 6.0% (RHA & FA, ASTM C618)	ASTM C114 (XRF)
SiO ₂ + Al ₂ O ₃ + Fe ₂ O ₃	29.9	91.1	88.5	2.5	≥ 70% (ASTM C618 for pozzolans)	ASTM C114 (XRF)

Note: Chemical composition was determined using X-ray Fluorescence (XRF) in accordance with ASTM C114. The requirements for the combined content of SiO₂ + Al₂O₃ + Fe₂O₃ (≥70%), SO₃ (≤5%) and Loss on Ignition (≤6%) for Rice Husk Ash and Fly Ash are

based on ASTM C618, which specifies the chemical requirements for natural pozzolans and Class F fly ash. Marble Powder is primarily a calcium carbonate filler material and is therefore not governed by ASTM C618 requirements.

Fine Aggregate

Natural river sand conforming to ASTM C33 was used as the fine aggregate in all concrete mixtures. Prior to batching, the sand was thoroughly cleaned to remove dust, clay particles and other deleterious organic impurities that could adversely affect the performance of concrete. Particle size distribution was determined through sieve analysis in accordance with ASTM C136, which confirmed that the sand satisfied the grading requirements of Zone II, making it suitable for structural concrete applications. The physical properties of the fine aggregate, including specific gravity, fineness modulus, water absorption, bulk density, moisture content and silt content, were evaluated before mix preparation.

Coarse Aggregate

Crushed stone with a nominal maximum particle size of 20 mm, conforming to ASTM C33, was used as the coarse aggregate in all concrete mixtures. The aggregates were clean, hard, durable, angular in shape, and free from deleterious substances such as clay, dust, silt and organic impurities that could adversely affect the performance of concrete. Prior to concrete production, the physical properties of the coarse aggregate, including specific gravity, water absorption, bulk density, fineness modulus, moisture content and aggregate crushing value, were determined in accordance with the relevant ASTM standards. The test results confirmed that the coarse aggregate satisfied the specification requirements for structural concrete applications.

Water

Clean potable water conforming to the requirements of ASTM C1602 was used for both concrete mixing and curing throughout the experimental program. The water was free from harmful contaminants, including chlorides, sulfates, organic matter, oils,

acids, alkalis and suspended solids, which could adversely affect cement hydration, concrete strength, or long-term durability. To minimize experimental variability and ensure consistency among all concrete mixtures, the same source of potable water was used for batching and curing all specimens. The quality of the mixing water satisfied the ASTM specifications for the production of structural concrete.

Expanplast SP100 Superplasticizer

Expanplast SP100, a polycarboxylate ether (PCE)-based high-range water-reducing admixture (HRWRA), conforming to ASTM C494 Type F, was used to enhance the workability of concrete mixtures containing supplementary cementitious materials. The admixture was incorporated at a dosage of 1% by weight of the cementitious materials in all modified concrete mixtures. The use of Expanplast SP100 improved the dispersion of cement particles, reduced water demand, enhanced flowability and minimized segregation while maintaining a constant water-to-cement ratio. The incorporation of the superplasticizer ensured adequate workability without compromising the mechanical performance or durability of the hardened concrete.

IV. CONCRETE MIX DESIGN

Concrete mixtures were prepared following the nominal mix proportion of 1:2:4 (cement: fine aggregate: coarse aggregate). A low water–cement ratio 0.45 was maintained throughout the study to produce high-strength concrete while minimizing capillary porosity. Different dosages of Expanplast SP100 were incorporated into the mixtures as given in Table 2, to evaluate their influence on hardened concrete properties.

Table 2: Mix Proportions of Concrete Mixtures

Mix ID	RHA (%)	FA (%)	MP (%)	Cement (kg/m ³)	Fine Aggregate (kg/m ³)	Coarse Aggregate (kg/m ³)	Water (kg/m ³)	SP100 (%)
CM	0	0	0	350	700	1400	227.5	0
RHA-5	5	0	0	332.5	700	1400	227.5	1
RHA-10	10	0	0	315.0	700	1400	227.5	1
RHA-15	15	0	0	297.5	700	1400	227.5	1
FA-5	0	5	0	332.5	700	1400	227.5	1
FA-10	0	10	0	315.0	700	1400	227.5	1
FA-15	0	15	0	297.5	700	1400	227.5	1
MP-5	0	0	5	332.5	700	1400	227.5	1
MP-10	0	0	10	315.0	700	1400	227.5	1
MP-15	0	0	15	297.5	700	1400	227.5	1
RHA+FA	5	5	0	315.0	700	1400	227.5	1
RHA+MP	5	0	5	315.0	700	1400	227.5	1
FA+MP	0	5	5	315.0	700	1400	227.5	1
RHA+FA+MP	5	5	5	297.5	700	1400	227.5	1

materials and superplasticizer on the mechanical performance of concrete.

V. EXPERIMENTAL PROGRAM

A total of fourteen concrete mixtures, comprising one control mixture and thirteen modified mixtures, were designed and prepared to evaluate the effects of Rice Husk Ash (RHA), Fly Ash (FA), Marble Powder (MP), and Expanplast SP100 on the fresh and hardened properties of concrete. The control mixture contained 100% Ordinary Portland Cement (OPC), whereas the modified mixtures incorporated different replacement levels of RHA, FA, MP, and their combined proportions while maintaining a constant water-to-cement ratio of 0.65.

Fresh concrete properties were assessed immediately after mixing using the slump test in accordance with ASTM C143. After casting, all specimens were demoulded after 24 hours and cured in potable water for 28 days before testing. The hardened concrete specimens were subsequently evaluated for compressive strength (ASTM C39), splitting tensile strength (ASTM C496), and flexural strength (ASTM C78) to determine the influence of the supplementary cementitious

VI. CASTING AND CURING

Concrete specimens were cast immediately after completion of the slump test. Cube molds (150 × 150 × 150 mm), cylindrical molds (150 × 300 mm) and prism molds (150 × 150 × 500 mm) were cleaned and lubricated before casting. Concrete was placed into the molds in layers and compacted using tamping rods and vibration techniques to eliminate entrapped air.

After casting, all specimens were covered with plastic sheets to prevent moisture loss and were demolded after 24 hours. The specimens were subsequently cured in clean potable water for 28 days before mechanical testing. Proper curing ensured continuous cement hydration and improved strength development.

VII. MECHANICAL TESTING

he hardened concrete specimens were tested after the designated curing periods using ASTM standard procedures.

Compressive Strength Test

The compressive strength of concrete was determined using 150 mm × 150 mm × 150 mm cube specimens in accordance with ASTM C39/C39M. For each concrete mixture, three cube specimens were cast and compacted using a vibrating table to eliminate entrapped air. After

casting, the specimens were covered to prevent moisture loss and demoulded after 24 hours. Subsequently, all specimens were cured in clean potable water at room temperature for 28 days before testing. Prior to testing, the cube specimens were removed from the curing tank, surface dried, and inspected for visible defects. The specimens were then placed centrally in a calibrated compression testing machine (CTM), and the compressive load was applied continuously at a uniform loading rate until failure. The maximum load at failure was recorded. All compressive strength values are given in Figure1.

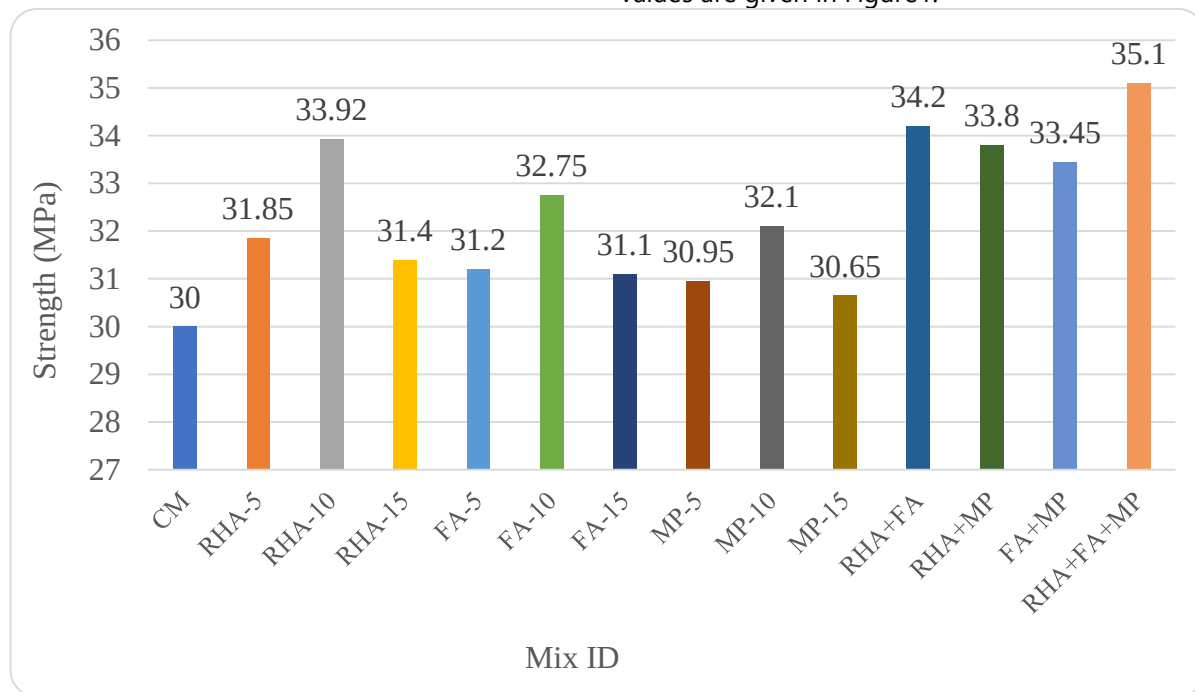


Figure 1. Shows Influence of RHA, Fly Ash, Marble Powder and Expanplast SP100 on Compressive Strength of Concrete

The 28-day compressive strength results of the control and modified concrete mixtures are presented in Figure 1. The incorporation of Rice Husk Ash (RHA), Fly Ash (FA), Marble Powder (MP), and their combined replacements significantly influenced the compressive strength of concrete. The results indicate that moderate replacement levels of supplementary cementitious materials significantly enhance the compressive strength of concrete. While individual replacement levels of 10% RHA, 10% Fly Ash, and 10% Marble Powder produced the

optimum performance among the single-material mixtures, the ternary blend containing 5% RHA, 5% Fly Ash, and 5% Marble Powder demonstrated the greatest improvement in compressive strength

Splitting Tensile Strength Test

The splitting tensile strength of concrete was determined in accordance with ASTM C496/C496M using cylindrical specimens measuring 150 mm in diameter and 300 mm in height. Three specimens were prepared for each concrete mixture and cured

in potable water for 28 days before testing. Prior to testing, the specimens were removed from the curing tank, surface dried and positioned horizontally between the loading platens of a calibrated compression testing machine (CTM). A continuous compressive load was applied along the

longitudinal axis of the cylinder until failure occurred. The applied load generated uniform tensile stresses perpendicular to the loading direction, causing the specimen to split along its vertical diameter. The maximum failure load was recorded. All splitting tensile strength values are given in Figure 2.

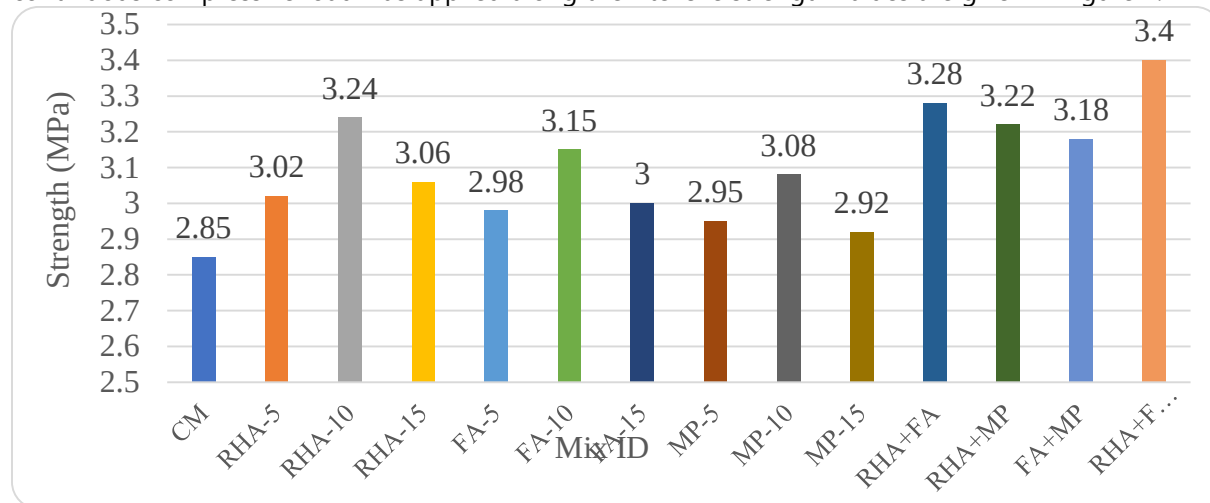


Figure 2. Influence of Rice Husk Ash, Fly Ash, Marble Powder and Expanplast SP100 on Splitting Tensile Strength

The 28-day splitting tensile strength results of the control and modified concrete mixtures are illustrated in Figure 2. The results indicate that the incorporation of Rice Husk Ash (RHA), Fly Ash (FA), Marble Powder (MP) and Expanplast SP100 improved the tensile performance of concrete compared with the control mixture. The control concrete exhibited a splitting tensile strength of 2.85 MPa, whereas all modified mixtures produced higher values, confirming the positive contribution of supplementary cementitious materials to crack resistance and bond development. Among the individual replacement mixtures, the concrete containing 10% RHA achieved the highest splitting tensile strength of 3.24 MPa, representing an increase of 13.68% over the control mix due to the pozzolanic reaction of RHA, which generated additional calcium silicate hydrate (C-S-H) gel and refined the pore structure. Similarly, the incorporation of 10% Fly Ash increased the tensile strength to 3.15 MPa, while 10% Marble Powder produced a value of 3.08 MPa, corresponding to improvements of 10.53% and 8.07%, respectively.

These enhancements are attributed to the pozzolanic activity of Fly Ash, the filler effect of Marble Powder, improved particle packing, and a denser interfacial transition zone between the cement paste and aggregates.

Flexural Strength Test

The flexural strength of concrete was determined in accordance with ASTM C78/C78M using prism specimens measuring 150 mm × 150 mm × 500 mm. Three beam specimens were prepared for each concrete mixture and cured in potable water for 28 days before testing. Prior to testing, the specimens were removed from the curing tank, surface dried and placed on the supporting rollers of a calibrated flexural testing machine. The test was conducted using the third-point loading method, in which two equal loads were applied symmetrically at one-third of the span length until failure occurred. This loading arrangement ensured a constant bending moment over the central portion of the beam and enabled an accurate evaluation of the concrete's resistance to bending.

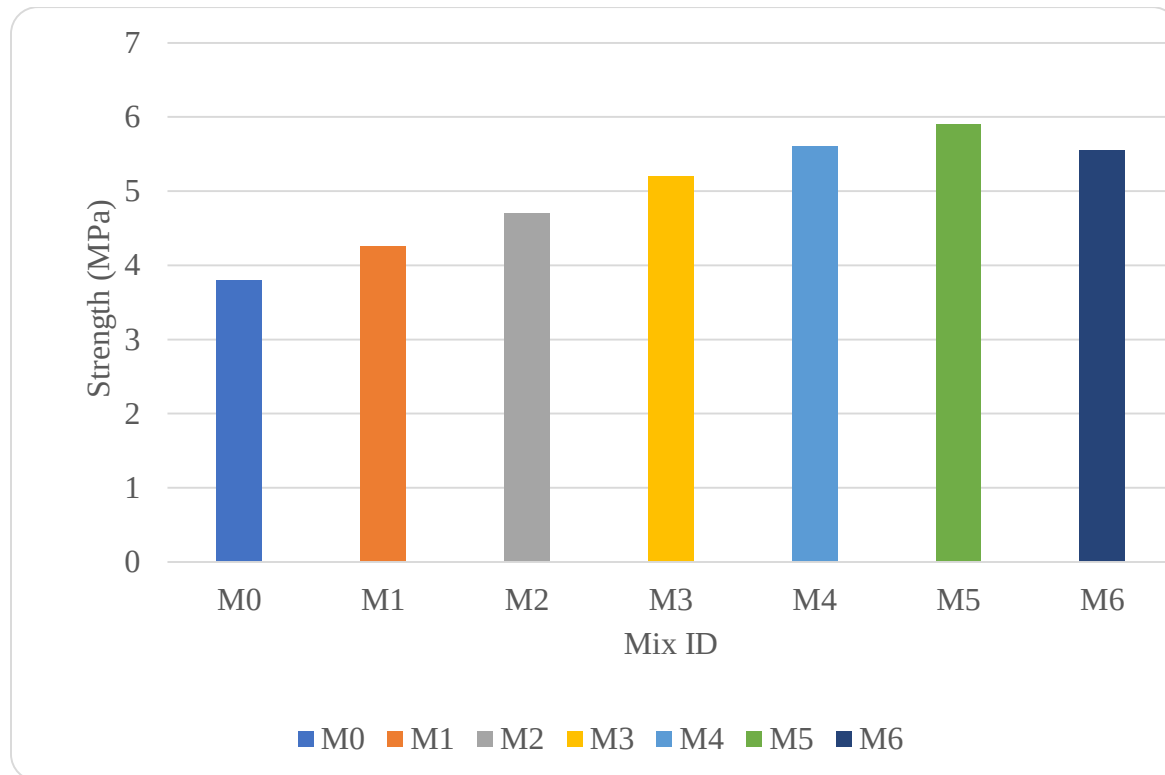


Figure 3. Represent Flexural Strength of Concrete at 28 Days

The flexural strength of concrete improved with the incorporation of Expanplast SP100, demonstrating the positive effect of the superplasticizer on the bending performance of concrete. The maximum flexural strength of 5.90 MPa was obtained at an admixture dosage of 2.5%, corresponding to increase of approximately 55.3% compared with the control mixture. This improvement is attributed to enhanced cement particle dispersion, reduced capillary porosity, improved hydration and a stronger bond between the cement paste and aggregates

at 2.5% by weight of cement. At this dosage, the concrete exhibited maximum strength and satisfactory workability due to improved cement particle dispersion and a denser microstructure. A slight reduction in strength was observed at the 3.0% dosage, indicating that excessive superplasticizer may adversely affect concrete performance. Overall, the study confirms that 2.5% Expanplast SP100 is the optimum dosage for producing high-strength concrete with enhanced mechanical properties.

VII. CONCLUSION

The present study evaluated the influence of Expanplast SP100 on the workability and mechanical properties of low water–cement ratio concrete. The results demonstrated that the incorporation of the superplasticizer significantly enhanced the fresh and hardened performance of concrete compared with the control mix. Compressive, splitting tensile and flexural strengths increased with increasing Expanplast SP100 dosage, reaching optimum values

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